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Indirect Plate Heat Exchangers offer Long Term Operating Performance

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Abstract

Twenty years ago a new technology was introduced to the fertilizer industry for cooling the final product before storage. The technology is based on indirect heat transfer using water cooled plates, instead of the rotary drum and fluid bed coolers which to that point were the industry standards. By eliminating large volumes of air, indirect plate exchangers offer the benefit of lower installed capital cost, much lower power consumption and reduced emissions. The result is significantly lower cost of ownership. Although the concept of the technology is simple, successful implementation requires a detailed knowledge of the science of indirect heat transfer, mass flow of bulk solids and the thermal characteristics of fertilizers. The technology is proven in more than 100 fertilizer plants worldwide in every type of fertilizer, nitrogen base, phosphates, potash and specialty fertilizers.

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1. Introduction

Approximately 20 years ago a new technology was introduced to the fertilizer industry, an indirect plate-type heat exchanger as the final cooling step before product storage. This method of cooling provided an alternative to the fluid bed or drum cooler which to that point was the industry standard.

The Indirect Plate Heat exchanger offers several major advantages compared to the fluid bed cooler (FBC) or cooling drum. The principal advantage is significantly lower energy consumption. There are also savings in installed capital cost by eliminating the large air handling system needed for the air coolers with chillers, fans, ducts and a scrubber. A further benefit, especially in retrofit projects, is the indirect plate cooler's small footprint compared with the large space requirement for a rotary drum or fluid bed cooler.

When the technology was first introduced to the industry, performance of the equipment was generally good in dry, temperate climates and when the product inlet temperature was relatively low (55 – 65°C). With higher inlet temperatures and hot humid climates, scaling and plugging would occur leading to the need for frequent cleaning and loss of production time.

The challenge to successful implementation of the plate exchanger is to fully understand the causes of scaling and caking as the product cools. Solex Thermal Science (formerly Bulkflow Technologies) has developed a full understanding of this mechanism and with this knowledge can design a fertilizer cooler to guarantee efficient cooling and long, reliable run time between scheduled cleaning.

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The references provide additional background to the development and application of indirect heat exchangers used in the fertilizer industry.

2. Long Term Operating Performance

The key to long term operation without unscheduled down time for cleaning is a thorough understanding of the mechanism which can lead to scaling and caking in the unit. The scaling and plugging mechanism is easy to understand in principle: moisture migrates from the fertilizer to the air in the void space between the particles, raising the relative humidity of the air. If the dewpoint of the air is above the temperature of the heat exchanger plates, condensation will occur on the plates. Dust in the product will combine with the condensate leading to scaling, loss of thermal performance, and rapid plugging of the unit. This mechanism is shown in Figure 1.

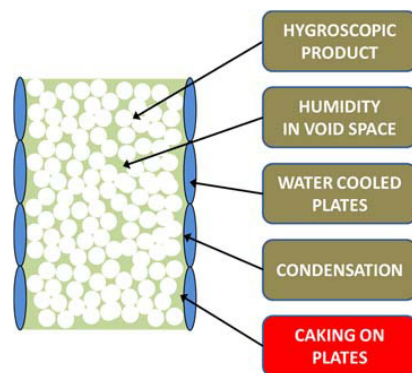


Figure 1- Scaling / Caking mechanism in fertilizer

2.1. Understanding the CRH Curve

The requirement is to prevent the condensation on the surface of the heat exchanger plates. The starting point is an understanding of the hygroscopic nature of fertilizers. In a hygroscopic product, there will be moisture transfer between the particles and the air in the void space between the particles. This is defined by the critical relative humidity (CRH) curve; each type of fertilizer has a unique CRH curve. A CRH curve for MAP, DAP and urea prills is shown in Figure 2.

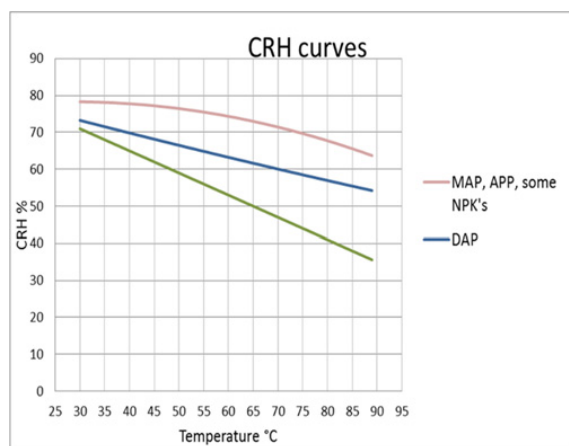


Figure 2 - CRH curves for MAP, DAP & Urea

The CRH curve is an equilibrium curve that plots Relative Humidity (RH) against Temperature. At each fertilizer temperature there is a corresponding RH, the RH is for the surrounding air. The curve shows that at a given temperature, if the RH of the air is above the line, moisture will migrate from the air into the product. If the RH of the air is below the line, moisture will migrate from the product into the air increasing the dewpoint of the air. If the dewpoint of the air surrounding the granules is above the water temperature, condensation will form on the exchanger plates leading to scaling and caking.

A simple solution to the problem is to increase the water temperature on the inside of the plates, this approach however results in a very inefficient thermal design. A much better solution is to add a small volume of purge air, this has a dilution effect on the air surrounding the granules resulting in lower dewpoints throughout the exchanger and the possibility to use correspondingly lower cooling water temperatures. This approach leads to a very efficient heat exchanger design. See Figure 3.

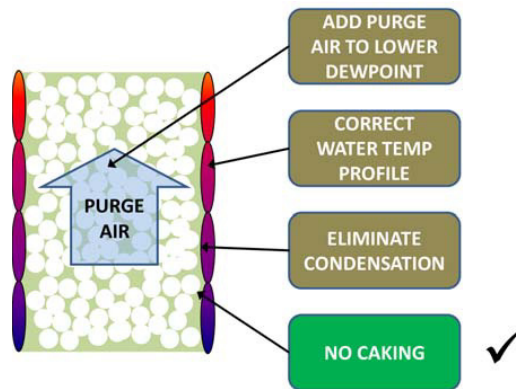


Figure 3 - Addition of Purge Air & Controlled Cooling Water Temperature Prevents Condensation

2.2. Accurate Thermal Modeling

The solution to caking described in the previous section, using a combination of a low volume purge air and elevated water temperatures, requires accurate thermal modelling. The primary heat transfer mechanism as a bulk product flows slowly between water cooled plates is conduction. Most conduction models are static, for example the conduction of heat through an insulating material. However in the case of an indirect heat exchanger, the model is not static, the product is flowing on one side and the water or fluid on the other side, in this regard the indirect solids exchanger is similar to a conventional shell and tube exchanger.

The solution to the heat transfer mechanism starts with the classic unsteady state heat conduction model defined by a Fourier Series such as the following:

$$Y = \frac{T_s - t}{T_s - t_o} = \frac{4}{\pi} \left[e^{-\left(\frac{\pi}{2}\right)^2 \frac{4af}{l^2}} \sin \pi \frac{x}{l} + \frac{1}{3} e^{-9\left(\frac{\pi}{2}\right)^2 \frac{4af}{l^2}} \sin \frac{3\pi x}{l} + \frac{1}{5} e^{-25\left(\frac{\pi}{2}\right)^2 \frac{4af}{l^2}} \sin \frac{5\pi x}{l} + \dots \right]$$

Where:

- T_s , t and t_o define a temperature profile
- a is thermal diffusivity (term combining specific heat, thermal conductivity and bulk density)
- f – time variable
- l – distance variable

A detailed definition of each of these terms is not given here since it is a standard text book equation and can easily be looked up in a heat transfer reference such as Kern.

The equation is solved for the dynamic situation found in an indirect bulk solids heat exchanger by an iterative approach to take into account the changing temperatures on both solid and fluid side. This approach works well in a computer simulation and Solex has developed advanced in-house software that defines product temperature at each point through the exchanger as the product cools. Figure 4 shows the temperature of solids and fluid at each point through each bank of the exchanger represented by percentages.

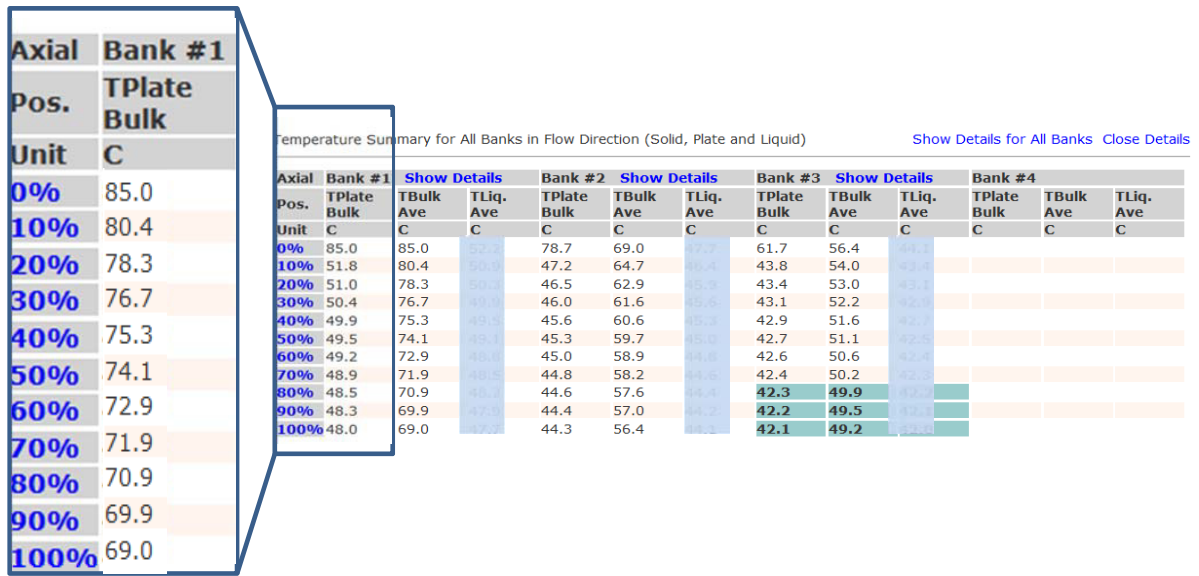


Figure 4 – Temperature profile of product as it passes through exchanger

The second requirement is to model the RH of the air in the void space including the addition of a small purge air flow. Combining this information allows for the optimum exchanger design to achieve highly efficient thermal performance, at the same time ensuring that the dewpoint of the air is below the water temperature at each point through the exchanger to prevent condensation.

The optimum heat exchanger design incorporates the following process requirements:

- Defined water temperatures. See Note 1 below.
- Purge air requirement (flowrate and dewpoint) – where possible ambient air is used to avoid the additional cost of producing dry air

Note 1: As the product cools, progressively cooler water temperature can be used; in other words counter-current water flow. Counter-current water flow in a heat exchanger is always the optimum design for maximum thermal efficiency.

2.3. A Complete System

To provide the correct operating conditions the exchanger system needs to incorporate a water temperature control module (WTCM) and a purge air system. WTCM provides the controlled water temperatures to the exchanger and the instrumentation/control function to provide optimum performance for different operating conditions. The purge air system provides air at the necessary flowrate and dewpoint. Often it is possible to operate with ambient air, but depending on the process conditions and location it may be necessary to use partially dry air. A typical schematic for the system is shown in Figure 5. This complete package is included as part of the Solex scope of supply.

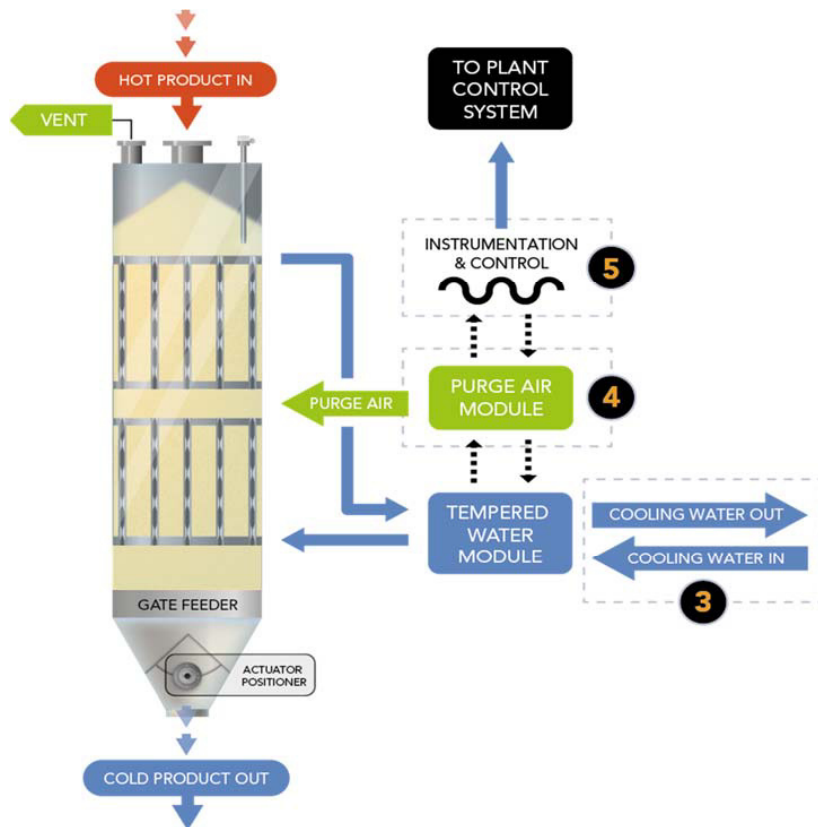


Figure 5 - Complete System with Exchanger, Water Temperature Control Module and Purge Air

3. Pilot Testing

Pilot trials were conducted at the OCP - Jorf Lasfar plant in Morocco in July 2012 to demonstrate the capability of the Solex heat exchanger for cooling DAP. The pilot test was set up to reproduce the real operating conditions by feeding directly from the entrance of the fluid bed and cooling the DAP to an outlet temperature below 50°C.



Figure 6 - Pilot Unit installed in Jorf Lasfar Plant

The objectives were to prove thermal performance in continuous mode and to demonstrate clean, trouble-free operation of the cooler. The results were very positive for all the repeated trials with outlet product temperatures as low as 42°C and very clean surfaces inside the cooler.



Figure 7 - Plates remained clean after run test

3.1. Pilot Test Results

Several runs were made over the test period simulating the process conditions of a full size unit, including water temperatures and purge air. The results show clearly that effective cooling can be achieved with no scaling or caking.

Table 1 - Pilot Test Results

Product				Water			
Steady-State for each run:	Averages			TOP	BOTTOM	Air	
	T° in	T° out	Rate	T° in	T° out		
	Run 1 (July 17)	66-74°C	44-58°C	180 kg/h	65-72°C	43-58°C	yes
	Run 2 (July 18)	71.5-74°C	45-46°C	230-370 kg/h	61°C	44-45°C	yes
	Run 3 (July 20)	63-72°C	39-44°C	200 kg/h	58.5-60°C	40-45°C	yes

3.2. Conclusion of Pilot Testing

Repeated trials consistently showed the same results. The real process conditions delivered product to the pilot unit and the outlet product temperatures achieved were well below 50°C. The pilot equipment remained entirely clean and trouble free for the duration of the trials.

This pilot test was very valuable to prove that the Solex indirect plate heat exchanger can effectively cool DAP to temperatures below 50°C and control the caking mechanism on all the surfaces inside the cooler. From Solex & OCP perspective, this pilot test was considered successful in demonstrating not only the cooling performance capability to replace a fluid bed, but also the overall suitability and trouble-free nature of the cooler for this application.

4. Design Considerations for Installation of Indirect Plate Heat Exchanger in MAP / DAP Plant

Typical process conditions for a MAP / DAP Cooler

Product Flowrate: 100 t/h
Product Size (Note 1): 1 – 4 mm

Product Temperature in: 85C
 Required Product Temp. out: < 50C
 Cooling Water (Notes 2 & 3): Cooling
 Tower
 Water at 28C

Figure 8 shows the approximate size for a MAP / DAP cooler with this rating. Note the small footprint, ideal for retrofit projects where space is limited.

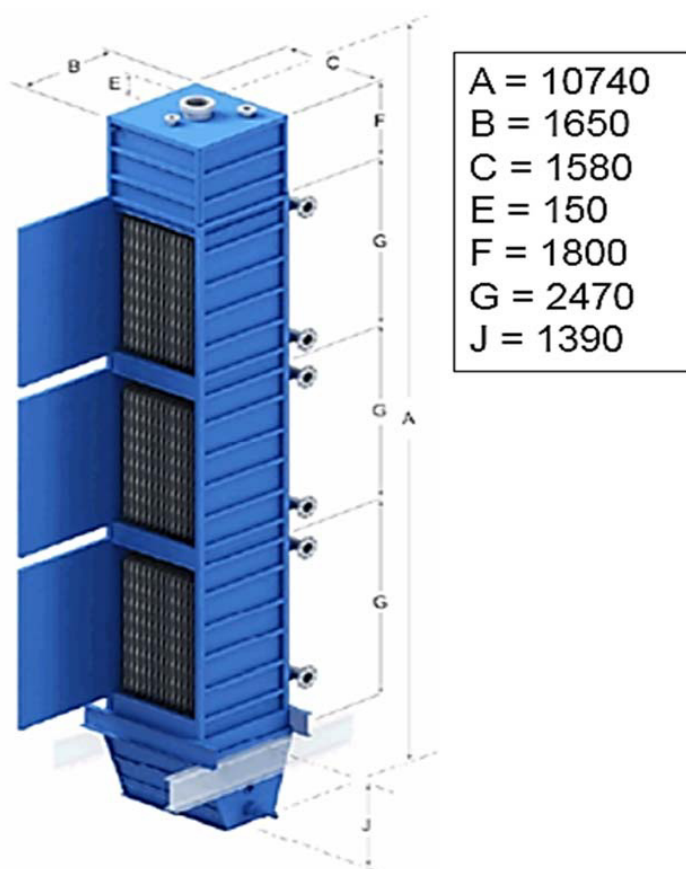


Figure 8

Notes re Installation:

1. The cooler would generally be installed immediately downstream of the sizing screens.
2. The cooling tower water supplies water to a water temperature control module that supplies the correct water temperatures to the MAP / DAP Cooler (arrangement previously shown in Figure 4).
3. The primary cooling water source can also be sea water. In this case a plate & frame heat exchanger is used, with the sea water on the primary side of the exchanger and a closed loop, demineralized water on the secondary side of the exchanger supplying the water to the MAP / DAP cooler. The plate & frame exchanger can be made of titanium, 254 SMO or other material suitable for sea water service.

5. Conclusion

The design of indirect heat exchangers for cooling fertilizers has significantly evolved over the 20 years since plate heat exchangers were first introduced to the industry. With a clear understanding of the science of fertilizer cooling the exchanger can be designed to fully meet the complex thermal requirements and achieve long run-times between scheduled cleaning. The Solex plate type exchanger is now proposed as a standard design by several fertilizer process licensing companies as part of their ongoing strategy to improve the overall operating efficiency of a state-of-the-art fertilizer manufacturing facility.

6. References

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